Performance of the Proof-of-Concept Multi-Beam Mask Writer (MBMW POC)

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ABSTRACT

Two proof-of-concept electron multi-beam mask writer tools (MBMW POC) have been realized, which are utilizing 262,144 programmable beams of 20nm beam size and 50keV beam energy to pattern 6’’ mask blanks. Tool characterization details and test results are outlined. Especially, LMS IPRO4 measurements (after development inspection) of short term and long term stability of the 82µm x 82µm beam array field are discussed. Scale stability of the beam array field of 0.1nm per day is demonstrated.

Keywords: electron, multi-beam, mask writer, template writer, direct wafer writer, MBMW, EBDW

1. INTRODUCTION

Pattern complexity is rising dramatically due to the fact that 193nm water immersion lithography is extended to the sub-20nm technology nodes. In order to make this extension work, leading edge masks require very aggressive optical proximity effect correction (OPC) and complex inverse lithography technology (ILT) patterns. To print these kinds of patterns properly with a state-of-the-art VSB (variable shaped beam) tool, however, very small shot sizes are needed, leading to an explosion of the total number of shots per mask. For the 18nm node, complex masks are already well beyond 1x10E12 shots per mask; i.e. ~4 T-shots for single patterning and ~1.5 T-shots for double patterning [1]. Such a 4 T-shot mask is predicted to translate to ~30h of write time using a VSB mask writer operating at 800 A/cm² [1]. Since the current trend shows an exponential increase in pattern complexity, linear improvements in mask writer performance will not be able to keep mask write times within acceptable limits. Furthermore, the mask exposure dose needs to be constantly increased – i.e. resist sensitivity needs to be decreased – in order to keep up with the stringent ITRS roadmap requirements regarding line width roughness (LWR) [2]. For example, for the 11nm HP mask technology node the exposure dose will need to be increased to ~50µC/cm² and for the 6nm HP mask technology node to ~100µC/cm² (see Figure 6).

Consequently, mask write times are bound to explode for conventional VSB mask writers for sub-20nm technology nodes due to the fact that the number of shots is increasing exponentially while the exposure dose needs to be increased at the same time. Linear performance improvements will to a large extend already be eaten up by the projected dose increase for future sub-20nm nodes. Therefore, there is a strong industrial need for a revolutionary improvement in mask writing technology, which is going to be provided by Multi-Beam Mask Writers (Figure 1) [3].

The IMS Multi-Beam Mask Writers (MBMW) provide currently 262,144 20nm-sized beams which are working in parallel. Due to the pixel-based exposure principle, throughput is completely independent of pattern complexity. Furthermore, the IMS MBMWs are designed from scratch for resist requiring >100µC/cm² dose, making them very well suited for the 11nm HP technology node and beyond [4,5].

The principles of the IMS proof-of-concept multi-beam mask writer (MBMW POC) and exposure results demonstrating multi-beam writing with 0.1nm address grid were published recently [5]. In 2013 IMS Nanofabrication successfully realized a second MBMW POC tool. This paper focuses on registration and stability results obtained with the 2 MBMW POC tools.

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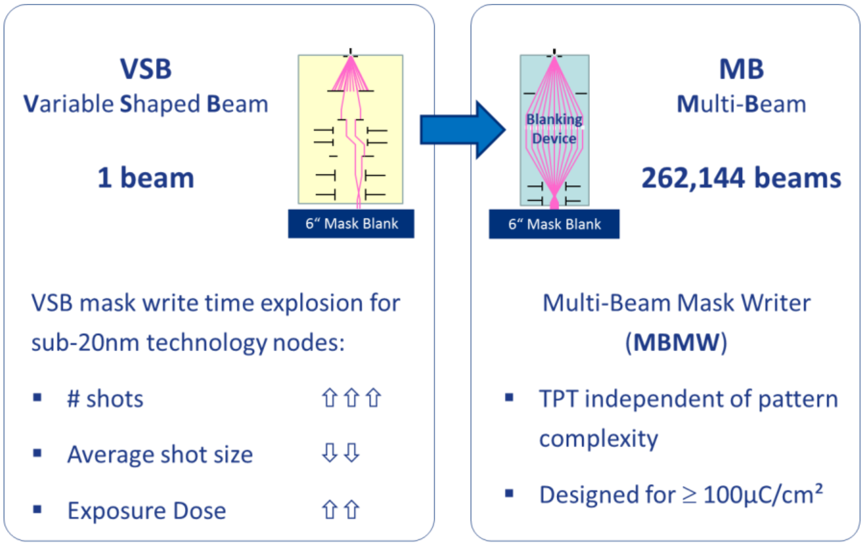


VSB
Variable Shaped Beam

1 beam

VSB mask write time explosion for sub-20nm technology nodes:

- # shots ⇧⇧⇧
- Average shot size ⇩⇩
- Exposure Dose ⇧⇧

MB
Multi-Beam

262,144 beams

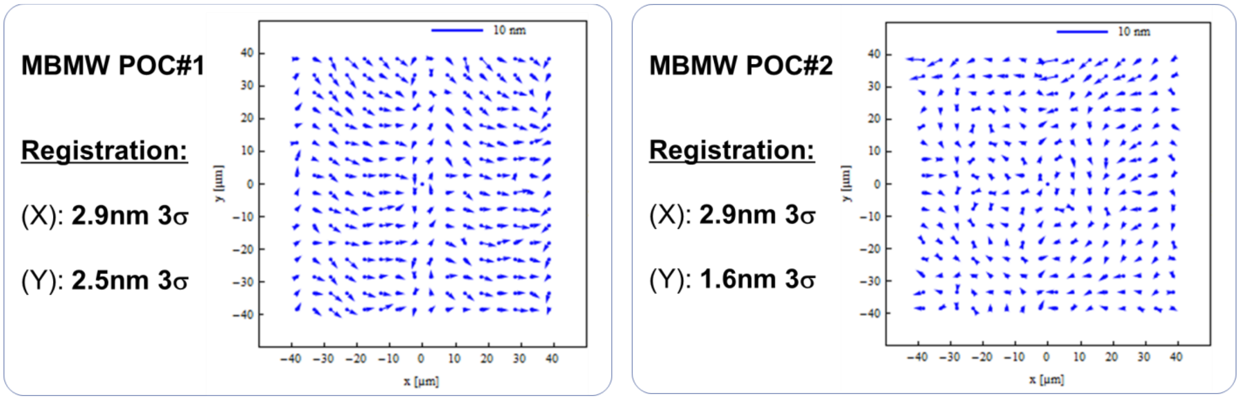
Multi-Beam Mask Writer (**MBMW**)

- TPT independent of pattern complexity
- Designed for ≥ 100µC/cm²

Figure 1: Change from 50keV electron VSB (variable shaped beam) to MB (multi-beam) mask writer tools

2. MBMW POC REGISTRATION

The MBMW POC beam array field consists of a 512 x 512 matrix of 262,144 programmable beams of 20nm beam size. The pitch between the beams is 160nm in X as well as in Y direction. Thus, the beam array field covers an area of 81.92µm x 81.92µm. With respect to "Registration" (placement accuracy relative to design), the MBMW POC specification target is to achieve 3.0nm 3sigma. This target was met for both MBMW POC tools as shown in Figure 2. Here, the locations of 16 x 16 crosses, which are evenly distributed across the whole 81.92µm x 81.92µm image field, were measured using an LMS IPRO4 metrology tool [6].



MBMW POC#1

Registration:

(X): **2.9nm 3σ**

(Y): **2.5nm 3σ**

MBMW POC#2

Registration:

(X): **2.9nm 3σ**

(Y): **1.6nm 3σ**

Figure 2: Registration within 82µm x 82µm beam array field: LMS IPRO4 measurements for POC#1 (left) and POC#2 (right). (The 1.3nm 3sigma LMS IPRO4 short term repeatability error [3] was taken out.)

Recently, *in-situ* calibration capability and an antifogging plate were added to the MBMW POC tool columns. These improvements are required to improve Registration further down to the 2.0nm 3sigma target of the first HVM tool.

3. SHORT TERM STABILITY OF THE MBMW POC TOOL

Figure 3 shows LMS IPRO4 measurement results of short term Registration stability (15min between exposures). The results are within the 1.3nm 3sigma short term repeatability error of the LMS IPRO4 metrology tool. Here, a reference grid is generated by averaging the 3 Registration stability measurement results and the deviations of the individual exposures from the reference grid are plotted in Figure 3.

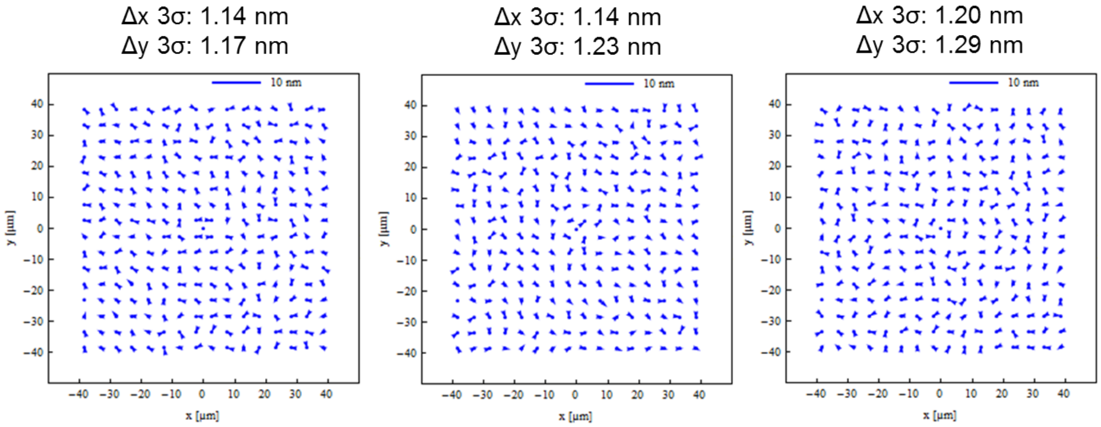
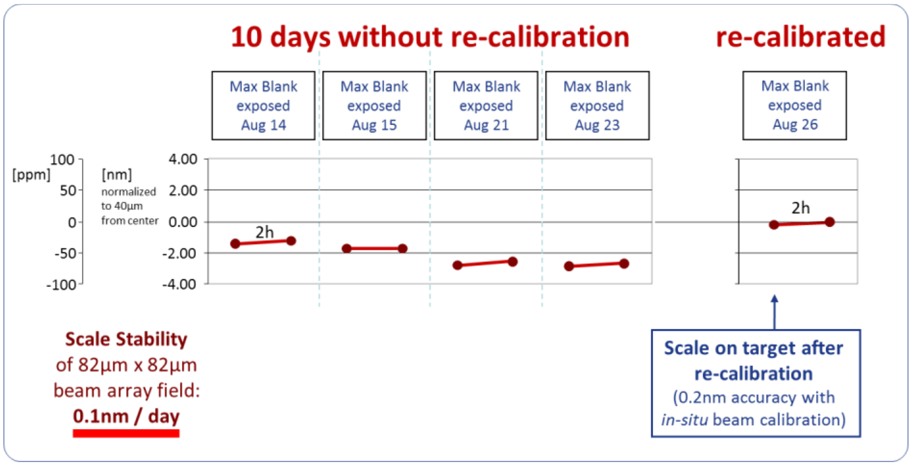


Figure 3: Short term Registration stability; LMS IPRO4 difference values of exposures within 15min time interval as obtained with the MBMW POC#2 tool.

4. LONG TERM STABILITY OF THE MBMW POC TOOL AND IN-SITU ADJUSTMENT

A long term stability test of the MBMW POC#1 tool was performed: The system was kept in operation for 10 days without any re-calibrations, exposing mask blanks on the days indicated in Figure 4.



Scale Stability of 82µm x 82µm beam array field: **0.1nm / day**

Scale on target after re-calibration (0.2nm accuracy with *in-situ* beam calibration)

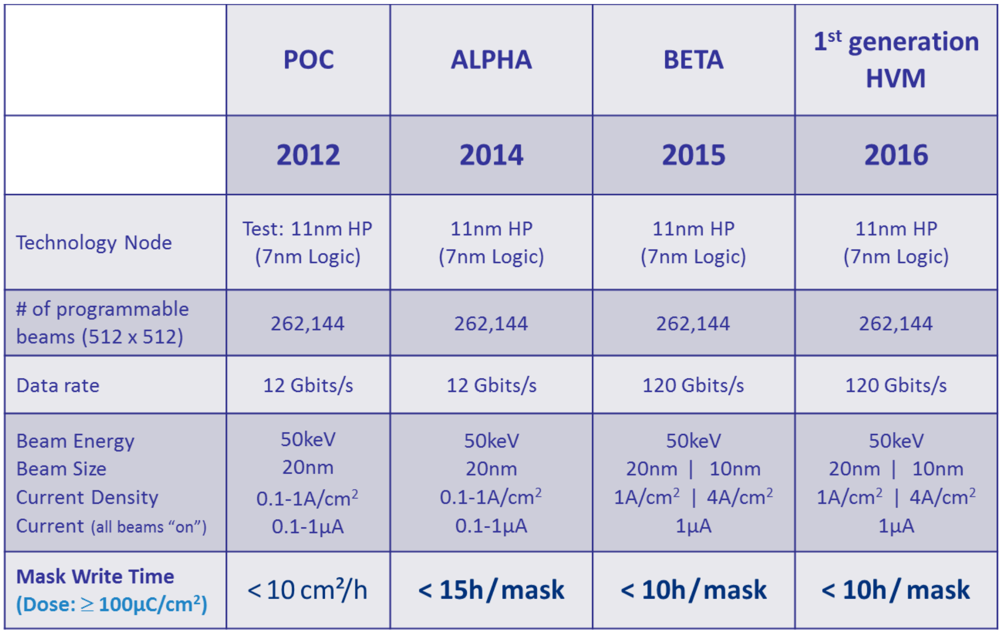
Figure 4: Long term stability of MBMW POC#1 tool and effectivity of in-situ scale calibration

The LMS IPRO4 measurements show that the scale of the 82µm x 82µm beam array was stable within 0.1nm per day.

Using *in-situ* beam calibration (which has an accuracy of 0.2nm), the scale was re-calibrated and a new mask blank was exposed. Subsequent LMS IPRO4 measurements demonstrated the success of in-situ scale re-calibration (Figure 4, right).

5. MBMW ROADMAP

The IMS MBMW roadmap is shown in Figure 5. The present focus is the MBMW Alpha tool, which combines one of the existing electron optical columns with a novel platform, featuring a laser interferometer controlled air-bearing vacuum stage.



	POC	**ALPHA**	**BETA**	**1st generation HVM**
	2012	**2014**	**2015**	**2016**
Technology Node	Test: 11nm HP (7nm Logic)	11nm HP (7nm Logic)	11nm HP (7nm Logic)	11nm HP (7nm Logic)
# of programmable beams (512 x 512)	262,144	262,144	262,144	262,144
Data rate	12 Gbits/s	12 Gbits/s	120 Gbits/s	120 Gbits/s
Beam Energy Beam Size Current Density Current (all beams "on")	50keV 20nm 0.1-1A/cm^2 0.1-1µA	50keV 20nm 0.1-1A/cm^2 0.1-1µA	50keV 20nm | 10nm 1A/cm^2 | 4A/cm^2 1µA	50keV 20nm | 10nm 1A/cm^2 | 4A/cm^2 1µA
Mask Write Time (Dose: ≥ 100µC/cm^2)	< 10 cm^2/h	**< 15h/mask**	**< 10h/mask**	**< 10h/mask**

Figure 5: MBMW roadmap

In parallel, two MBMW Beta tools are being realized where the column can provide 262,144 programmable beams of 20nm or 10nm beam size (with *in-situ* means for changing the beam size [7, Figure 2]). In order to maintain productivity, the current density is enhanced to 4A/cm^2 when operating the column with 10nm beams, thus obtaining 1µA current (with all beams "on"). Concurrently, the data path speed is enhanced from presently 12Gbits/s to 120Gbits/s. The first generation HVM (high volume manufacturing) MBMW tools are planned to be delivered in 2016.

Throughput of the MBMW tools is independent of pattern data complexity. Furthermore, the MBMW Beta and HVM tools are designed from scratch to achieve <10h mask write times using 100µC/cm^2 resists.

6. MBMW EXTENDIBILITY TO SUB-10NM HALF-PITCH TECHNOLOGY NODES

There is the need to enhance the resist exposure dose in order to meet the ITRS requirements on low line edge and line width roughness (LER/LWR), as shown in Figure 6. At the same time, there is the need to provide a low column as well as low resist blur so that the total 1sigma blur is < 10nm (see Figure 6).

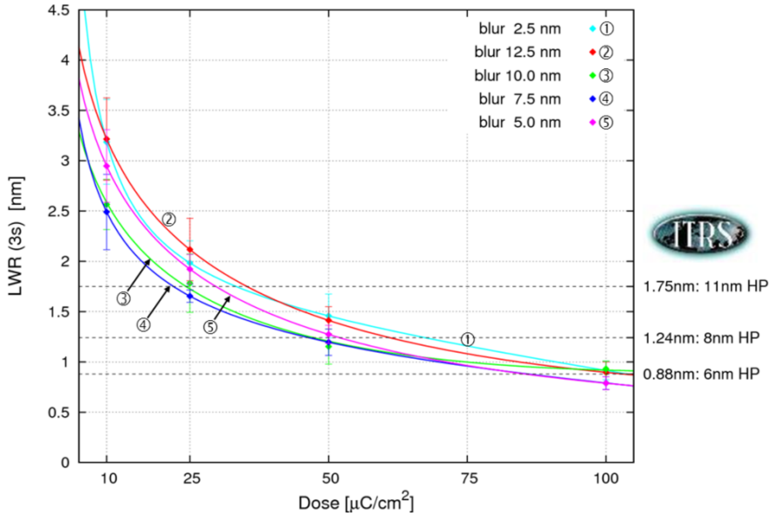


Figure 6: Monte Carlo simulation of the 3sigma line width roughness (LWR) for 30nm line width vs. exposure dose. Parameter is the combined tool and resist 1sigma blur. The optimum total 1sigma blur is between 5nm and 7.5nm, meeting the requirements for the 6nm HP mask technology node when using a resist exposure dose of 100µC/cm^2.

The realized MBMW column has a 1sigma blur of 5nm, which was also verified experimentally [7, Figure 4]. Figure 7 shows the different column blur contributions as well as the total column blur, which is virtually current-independent. Thus, in combination with a suitable resist material, the realized column is suitable for the 8nm HP and 6nm HP mask technology nodes.

In order to meet the same throughput targets for the sub-10nm nodes using smaller beam sizes, there is the potential to increase the number of programmable beams to ca. 0.5Mio beams for the 8nm HP mask technology node and to ca. 1Mio beams for the 6nm HP mask technology node.

Therefore, from a throughput as well as a blur perspective, the IMS MBMW technology is well suited to meet the sub-10 nm HP technology node requirements.

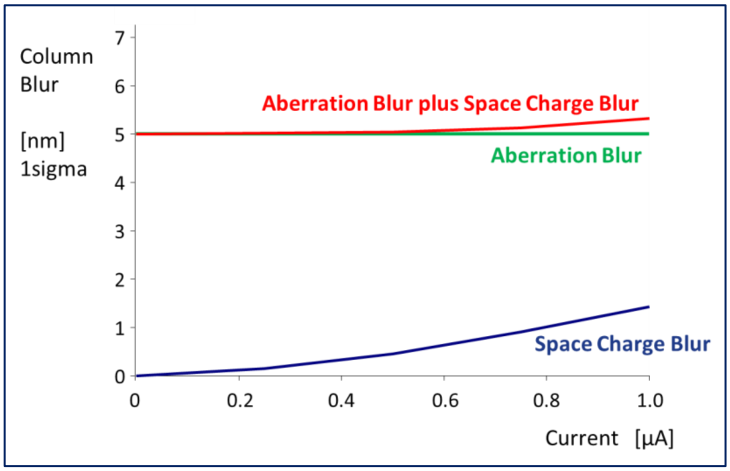


Figure 7: Contributions to the 1sigma blur of the realized multi-beam column

7. SUMMARY

Two MBMW POC systems were realized and used to confirm multi-beam writing principles and to demonstrate lithographic performance. The key results are listed below:

- Registration is within 3nm 3sigma POC target specifications, optimization to 2nm 3sigma in progress
- Short term (15min) stability of the POC column distortion fingerprint is within the measurement accuracy of the metrology tool (LMS IPRO4).
- Scale stability of the POC column was found to be < 0.1nm per day. *In-situ* recalibration works within the specified accuracy of 0.2nm.
- 5nm 1sigma column blur was achieved across 82µm x 82µm beam array field with 262,144 programmable beams of 20nm size and 50keV energy allowing to meet the stringent ITRS requirements for LWR for the sub-10nm mask technology nodes.
- For IMS MBMW tools, throughput is independent of pattern complexity.
- Multi-beam writing with 0.1nm address grid was demonstrated in pCAR as well as HSQ.

The program is on track for the MBMW Alpha tool in 2014, for Beta in 2015 and 1st generation HVM tools in 2016.

There is MBMW extendibility to sub-10nm mask technology nodes:

- Resolution and blur of the realized electron optical column are well suited for the 8nm HP and 6nm HP technology nodes
- A novel platform with air-bearing vacuum stage is used which meets the sub-10nm HP requirements
- The number of programmable beams can be increased to ca. 0.5Mio for the 8nm HP mask technology node, and to ca. 1Mio for the 6nm HP technology node

⇨ IMS MBMW tools will be able to achieve < 10h mask write times for sub-10nm mask technology nodes.

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